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(71) Applicant
Westland plc
(United Kingdom)
Westland Works
Yeovil
Somerset
(72) Inventor
Alastair Alexander Brown
(74) Agent and/or Address for Service
Forrester Ketley & Co
Forrester House
52 Bounds Green Road
London N11 2EY

(54) **Apparatus for detecting the onset of cracks or fractures**

(57) Apparatus for detecting the onset of a crack in a structural member or mechanical component 11 comprises one or more optical fibres 12 arranged to transmit light emitted by one or more self-luminous light sources 13 to light sensitive detector means such as a photo-electric cell 14. Each optical fibre is attached to the member or component or, in the case of a member or component manufactured from composite materials, it may be embedded within the member or component. A crack propagating in a region of the member or component to which the optical fibre is attached will cause the fibre to fail so that light will not be transmitted to the light sensitive detector means which is arranged to activate a warning device.

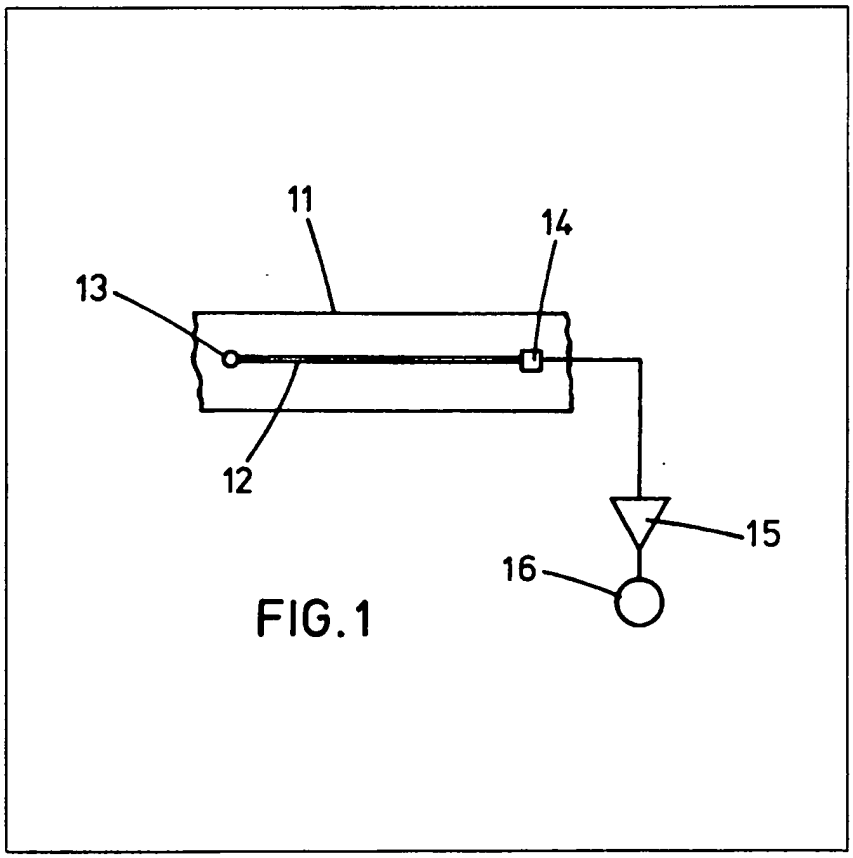

FIG.1

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The references to (Figs. 8 and 9 of) the drawings in the printed specification are to be treated as omitted under Section 15(3) of the Patents Act 1977.

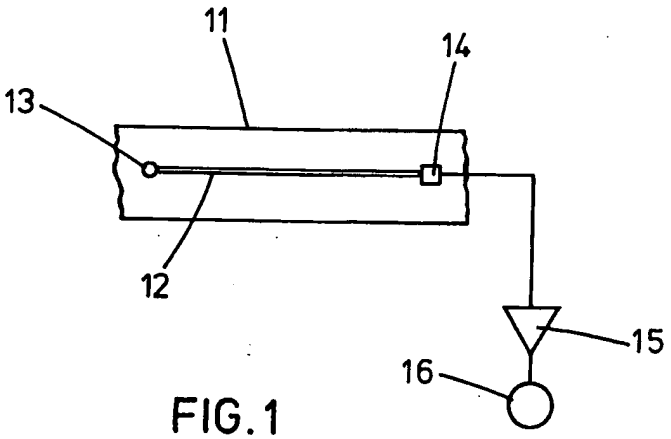

FIG.1

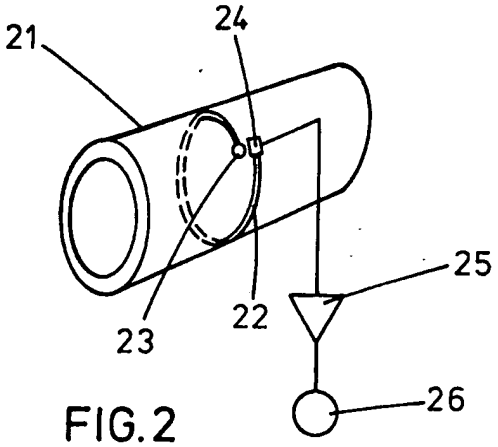

FIG.2

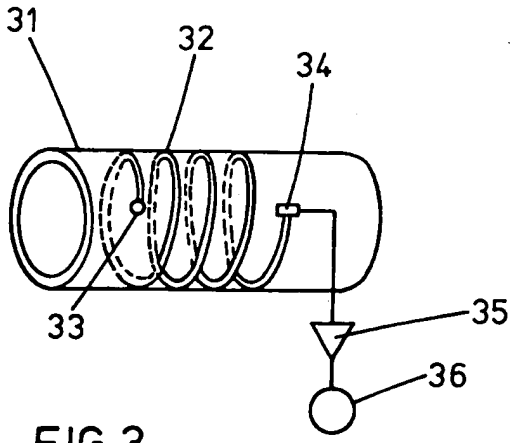

FIG.3

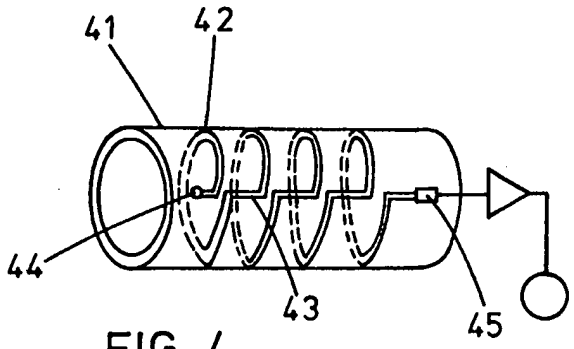

FIG. 4

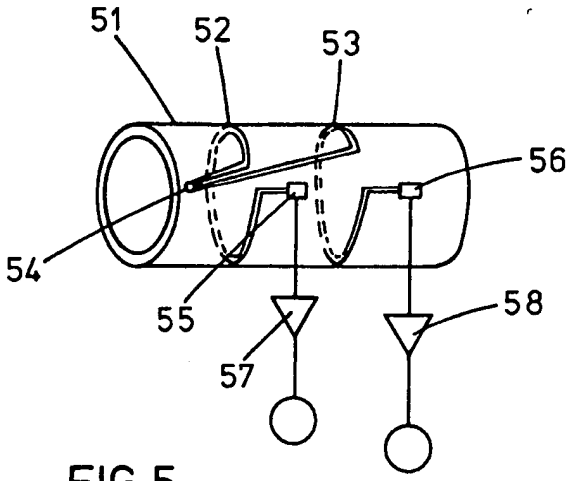

FIG.5

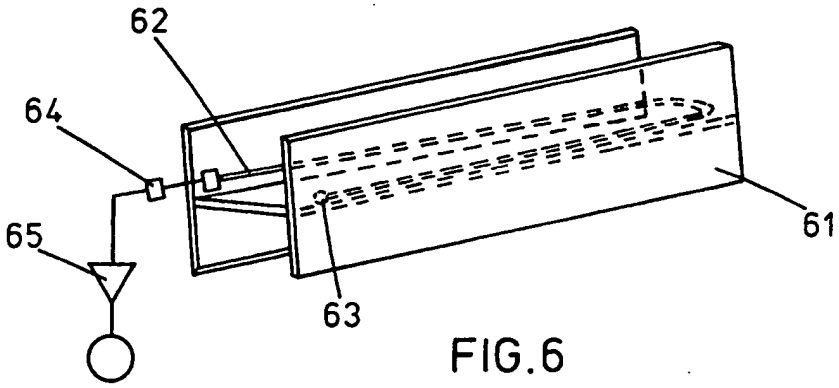

FIG.6

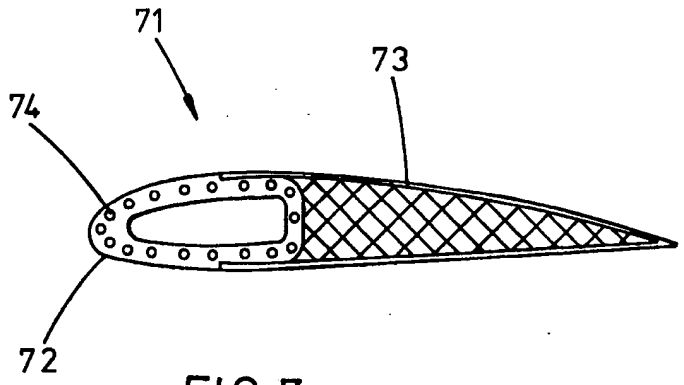

FIG.7

SPECIFICATION

Apparatus for detecting the onset of cracks or fractures

THIS INVENTION relates to apparatus for detecting the onset of cracks or fractures in structural members and mechanical components.

Recent experience in the North Sea and elsewhere has shown that catastrophic failures of oil rig or drilling platform legs have been preceded by the development of cracks or fractures of considerable magnitude in structural members. Regular inspection by direct or indirect visual methods are laborious, time-consuming and expensive. These problems are further accentuated when a structural member to be inspected is immersed in water at depths of up to 200 metres (600 feet). For example, it has been proposed to measure the loads in such structures using strain gauges attached to at least the main load carrying members of the structure but a particular disadvantage is that a source of electrical power is required for their operation. If electrical power is provided from a source located above the surface of the water then a particular difficulty is found in providing adequate protection against ingress of water into electrical wiring, particularly at the position of any joints, located below the surface of the water. A battery power pack attached to the structure close to the position of any strain guages partly overcomes the problem insofar as supply of power to the strain gauges is concerned but electrical signals output by the gauges must still be passed to the surface for amplification and display. Also, the battery power pack has limited life and must be changed from time to time, requiring the use of divers.

Similar problems occur in detecting the onset of cracks in aircraft structures and mechanical components. Visual inspection is only possible when the aircraft is at rest on the ground and it is often the case that high load carrying areas of the structure are inaccessible for visual inspection. Furthermore it is desirable that some means should be provided of indicating the onset of a crack whilst the aircraft is in flight. Any detection apparatus that relies upon electrical power is only as reliable as the electrical system and any malfunction of the electrical system may lead to unnecessary termination of an operational flight.

According to the present invention apparatus for detecting the onset of a crack in a structural member or mechanical component comprises an optical fibre adapted for attachment to said structure or component and a self-luminous light source adapted for location at one end of said optical fibre so that light emitted by said light source is transmitted along said optical fibre to provide an indication of the integrity of said member or component by emission from the opposite end of said optical fibre.

The onset of a crack in any part of the structural member or mechanical component to which the optical fibre is attached will cause the optical fibre to fracture so that light from the self-luminous light source will cease to be emitted from the opposite end of the fibre providing an indication of the onset of the crack. The opposite end of the optical fibre may be presented for visual observation but is preferably associated with a light sensitive detector such as, for example, a photoelectric cell, which is energised by emitted light to produce an electrical signal. The electrical signal may be fed to an electrical circuit for suitable amplification and use in holding open a relay which when closed activates a visual or audio warning device.

The self-luminous light source may be of the type comprising a sealed hollow glass body having an internal phosphor coating excited to luminescence by a gaseous radionucleide contained within said hollow glass body. One such light source is that manufactured by Saunders-Roe Developments Limited and sold under their trade name "BETALIGHT" and their registered trade mark "SRDL BETALIGHT".

The self-luminous light source may be mounted on the structural member or mechanical component adjacent an end of the optical fibre which terminates on the member or component. Alternatively, the self-luminous light source may be mounted adjacent to an end of the optical fibre which is remote from the member or component.

Similarly, when a light sensitive detector is used to detect light at the opposite end of the optical fibre, the light sensitive detector may be mounted on the member or component adjacent an end of the optical fibre and connection may be made between the light sensitive detector and an amplifier which is remote from the member or component, or, alternatively, the light sensitive detector may be mounted adjacent an end of the optical fibre which is remote from the member or component.

The self-luminous light source may provide light for more than one optical fibre attached to the structural member or mechanical component.

The optical fibre may be attached to run parallel to any major load carrying path of the structural member or mechanical component, or it may be wound around the member or component in the manner of a coil.

When the optical fibre is attached to a structural member forming part of an oil rig or similar structure which is to be partially immersed in water, the optical fibre may be fixed to the structural member by a mastic compound or similar substance at regular in-

tervals along the structural member prior to painting of the structure. The paint used for such structures and subsequently applied is sufficiently tactile to completely cover the optical fibre and effectively bond it to the surface of the structural member.

The present invention also extends to a structural member or component manufactured from composite materials and having one or more optical fibres embedded within said member or component, the or each said optical fibre having one end positioned for receiving light emitted by a self-luminous light source and an opposite end positioned for directing light transmitted along said optical fibre onto light sensitive means so as to provide an indication of the integrity of the member or component. A particular example is a composite main rotor blade for a helicopter which may have a plurality of optical fibres embedded within the composite material and may have one end of each optical fibre adapted to receive light from one or more self-luminous light sources mounted at the tip end of the blade and one or more light sensitive detectors mounted for receiving light from the opposite ends of the optical fibres which terminate at or near the root end of the blade.

In an aircraft application detection apparatus in accordance with the present invention may be used to monitor all critical areas of the aircraft. For example, in application to a helicopter, optical fibres and self-luminous light sources may be associated with the main rotor blades, the tail rotor blades, structural mounting members for the engines and gear box, and highly stressed areas of the cabin and tail cone structure, warning of the onset of cracking in any of these components or areas being provided on a display located at the pilot's instrument panel or by audio warning given to the pilot.

The invention will now be further described by way of example only and with reference to the accompanying drawings in which,

Figure 1 shows apparatus in accordance with the invention when used to detect cracks in a structural member;

Figures 2, 3, 4 and 5 show apparatus in accordance with various embodiments of the invention when used to detect the cracks in a tubular structure member;

Figure 6 shows apparatus in accordance with the invention when used to detect cracks in an H-section girder;

Figure 7 shows a transverse cross-section through a helicopter main rotor blade manufactured from composite materials and incorporating apparatus in accordance with the invention;

Figure 8 shows apparatus in accordance with the invention when used to detect cracks in a welded joint between two tubular structural members; and

Figure 9 shows apparatus in accordance with the invention when used to detect cracks in a riveted joint between two structural members.

Referring to Fig. 1, a longitudinally extending structural member 11 has an optical fibre 12 extending parallel to the longitudinal axis of the member 11, attached thereto by a suitable substance such as mastic putty (not shown) at regular intervals along the length of the optical fibre 12 prior to painting of the structural member 11. A self-luminous light source 13, preferably comprising a hollow glass body having an internal phosphor coating excited to luminescence by a gaseous radionucleide sealed within the hollow glass body, is mounted on the structural member 11 adjacent to one end of the optical fibre 12 so that light emitted by the self-luminous light source 13 is directed onto the end of the optical fibre 12. A light sensitive detector 14, for example a photo-electric cell, is mounted on the structural member 11 adjacent the opposite end of the optical fibre 12 so as to receive light transmitted along the optical fibre 12 from the self-luminous light source 13 and emitted from the opposite end. The light sensitive detector 14 is energised by this light to produce an electrical signal which is fed to an amplifier 15 and output from the amplifier 15 is fed to a warning device 16; for example, the output from the amplifier may be used to energise a relay so that in the absence of a light signal there will be no electrical output from the amplifier and the relay will release to activate a warning mechanism such as an audible warning device. This embodiment is suitable for detecting cracks propagating transversely of the structural member 11.

Fig. 2 shows part of a tubular structural member 21 of circular cross-section having an optical fibre 22 attached to and extending around the circumference of the external surface of the member 21. The ends of the optical fibre are arranged to slightly overlap and a self-luminous light source 23 is mounted on the structural member adjacent one end of the optical fibre 22 whilst a light sensitive detector 24 is mounted on the member 21 adjacent to the opposite end of the optical fibre 22. As for the embodiment of Fig. 1 an electrical signal from the light sensitive detector 24 is fed to an amplifier 25 and output from the amplifier 25 is used to activate a safety warning device 26. This embodiment would be used to detect cracks propagating along the length of the member 21 substantially parallel to its longitudinal axis.

Fig. 3 shows a tubular structural member 31 of circular cross section having an optical fibre 32 helically wound around the circumference of the external surface of the member 31. One end of the optical fibre 32 is adjacent to a self-luminous light source 33 and the opposite end is adjacent to a light sensitive detector 34. As in previous embodiments

an electrical signal from the light sensitive detector 34 is fed to an amplifier 35 and output from the amplifier 35 is used to activate a safety mechanism 36. The principal application of this embodiment is in detecting cracks propagating substantially parallel to the longitudinal axis of the member 31; however, if the optical fibre is close coiled it may also detect cracks propagating transversely of the member 31.

Fig. 4 is an embodiment similar to Fig. 3 in which a single optical fibre 42 is coiled around the external surface of a structural member 41 so as to extend over at least part of its length. However, in the embodiment of Fig. 4 each coil of the optical fibre 42 merges with the next adjacent coil by having a portion 43 of the length of the optical fibre 42 extending substantially parallel to the longitudinal axis of the structural member 41. One end of the optical fibre 42 again terminates adjacent to a self-luminous light source 44 whilst the other end of the optical fibre 42 terminates adjacent to a light sensitive detector 45. The arrangement of the optical fibre 42 in this embodiment provides for the detection of cracks propagatng either transversely or longitudinally of the structural member 41.

Fig. 5 shows a tubular structural member 51 of circular cross section having two optical fibres 52 and 53 wound around the circumference of the external surface of the structural member 51 and spaced from each other along its length. One end portion of each optical fibre 52 and 53, respectively, is bent so as to terminate adjacent to a common self-luminous light source 54 mounted on the structural member 51. The opposite ends of the optical fibre 52 and 53 respectively, terminate adjacent to individual light sensitive detectors 55 and 56, respectively. An electrical signal from the light sensitive detector 55 is fed to an amplifier 57 whilst that from the light sensitive detector 56 is fed to an amplifier 58.

Fig. 6 shows an H-section girder 61 having an optical fibre 62 extending from one end of the girder 61 along the length of the girder and being located in the junction between the web of the girder and one of its flanges. At the opposite end of the girder 61 the optical fibre extends transversely of the web and then returns along the length of the girder in the junction between the web and the opposite flange of the girder. A self-luminous light source 63 is mounted on the girder 61 adjacent to one end of the optical fibre 62 and a light sensitive detector 64 is located opposite the other end of the optical fibre 62, an electrical signal output from the light sensitive detector 64 being fed to an amplifier 65.

Fig. 7 shows a transverse cross section through a helicopter main rotor blade 71 comprising a main load carrying spar 72 and a trailing edge fairing structure 73. The spar 72 is manufactured from resin impregnated glass and carbon composite laminates. During manufacture of the spar when laying up the glass and carbon composite laminates optical fibres 74 are laid between the laminates so as to extend over the length of the blade from the root end to the tip end. If desired each optical fibre 74 may return upon itself so that both ends of the optical fibre are positioned at the root end of the blade. One end of each optical fibre is arranged to receive light from a self-luminous light source (not shown in Fig. 7) whilst the opposite end of each optical fibre 74 is arranged to terminate adjacent a light sensitive detector (not shown in Fig. 7). Each optical fibre 74 may be arranged to receive light from an individual self-luminous light source or, alternatively, a self-luminous light source of suitable shape may be arranged to transmit light to a plurality or all of the optical fibres 74. Electrical signals from the light sensitive detectors may, after suitable amplification, be used to energise one or more relays that in the absence of a signal release to energise a warning device.

Fig. 8 illustrates application of apparatus in accordance with the present invention as a means of detecting cracks propagating in a welded joint between two tubular structural members 81*a* and 81*b*, respectively, meeting each other at an included angle of, say, 120 degrees. Adjacent end portions of the members 81*a* and 81*b* are entered into tubular sleeves 82*a* and 83*b*, respectively, and are joined thereto by welding 83*a* and 83*b*, respectively. The adjacent ends of the tubular sleeves 82*a* and 82*b* are joined by welding 84. An optical fibre 85 having one end adjacent to a self-luminous light source 86 mounted on the member 81, extends along the sleeve 82*a* and 82*b* so as to pass over the welds 83*a*, 84 and 83*b*, before being bent to return upon itself and again pass over the welds 83*b*, 84 and 83*a*, to terminate at an opposite end which is adjacent to a light sensitive detector 87 mounted on member 81*a*. As in previous embodiments light transmitted along the optical fibre 85 from the self-luminous light source 86 is converted by the light sensitive detector 87 into electrical signals which are amplified by amplifier 88 before being passed to a warning device 89.

Fig. 9 illustrates application of apparatus in accordance with the present invention in detecting cracks propagating in riveted or bolted joints. In the embodiment of Fig. 9 two U-section frame members 91*a* and 91*b* are joined by riveting with a gusset plate 92. An optical fibre 93 is attached to the gusset plate 92 between spaced lines of rivets 94 and 95. The optical fibre 93 runs close to and parallel with the line of rivets 94 and is then bent to return upon itself and run close to and parallel with the line of rivets 95. One end of the optical fibre terminates adjacent to a self-

luminous light source 96 and the opposite end terminates adjacent to a light sensitive device 97. Electrical signals output by the light sensitive device 97 are amplified by amplifier 98 before being passed to a warning device 99.

In all of the described embodiments, in the event that a crack propagates in any part of a structural member to which an optical fibre is attached, the optical fibre will also fracture so that light will not be transmitted from the self-luminous light source to the light sensitive detector. The absence of any electrical signal from the light sensitive detector is then used to activate a suitable warning device.

A major advantage of the present invention will be seen to be that no source of electrical power is required for operation of the failure detection apparatus in accordance with the invention.

CLAIMS

1. Apparatus for detecting the onset of a crack in a structural member or mechanical component, comprising an optical fibre adapted for attachment to said member or component and a self-luminous light source adapted for location at one end of said optical fibre so that light emitted by said light source is transmitted along said optical fibre to provide an indication of the integrity of said member or component by emission from the opposite end of said optical fibre.

2. Apparatus as claimed in Claim 1, further comprising light sensitive detector means adapted for location adjacent said opposite end of said optical fibre so as to be energised by light emitted therefrom to produce an electrical signal, and electric circuit means connected with said light sensitive detector means and an audio/visual warning device.

3. Apparatus as claimed in Claim 2, wherein said light sensitive detector means comprises a photo-electric cell.

4. Apparatus as claimed in any preceding Claim, comprising a plurality of optical fibres adapted to receive light emitted by one or more self-luminous light sources.

5. Apparatus as claimed in any preceding Claim, wherein said self-luminous light source comprises a sealed hollow glass body having an internal phosphor coating excited to luminescence by a gaseous radionucleide contained within the hollow glass body.

6. A structural member or component manufactured from composite materials, one or more optical fibres embedded within said member or component, the or each said optical fibre having one end positioned for receiving light emitted by a self-luminous light source and an opposite end positioned for directing light transmitted along said optical fibre onto light sensitive means so as to provide an indication of the integrity of the member or component.

7. A component as claimed in Claim 6, comprising a helicopter rotor blade.

8. A structural member fitted with apparatus for detecting the onset of cracks substantially as hereinbefore described with reference to and as shown in Fig. 1 or Fig. 6 of the accompanying drawings.

9. A tubular structural member fitted with apparatus for detecting the onset of cracks, substantially as hereinbefore described with reference to and as shown in any one of Figs. 2, 3, 4 or 5 of the accompanying drawings.

10. A welded joint between two tubular structural members fitted with apparatus for detecting the onset of cracks, substantially as hereinbefore described with reference to and as shown in Fig. 8 of the accompanying drawings.

11. A rivetted joint between two structural members when fitted with apparatus for detecting the onset of cracks substantially as hereinbefore described with reference to and as shown in Fig. 9 of the accompanying drawings.

12. A helicopter main rotor blade manufactured from composite materials and incorporating apparatus for detecting the onset of cracks, substantially as hereinbefore described with reference to and as shown in Fig. 7 of the accompanying drawings.

13. Every novel feature and every novel combination of features disclosed herein.

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